Fire Examination Reports and FAA Testing Reports

Fire Examination Report
(Original On-scene 7/6/13)

Fire Damage Documentation (Al Carlo, Boeing)

External Documentation
The crown was burned through from approximately Door 1 (STA 410) to Door 2 area (STA 951) and Door 2 area (STA1056) to Door 3 (STA 1497).

Engine number 2 ended up with its 6 o'clock position against the fuselage on the right side of airplane at STA 825, next to a bay without a window (due to ECS riser ducts).

Figure 1. Photograph of accident aircraft.

There were varying amounts of skin discoloration and heating from STA 718 to STA 930. The door 2R external skins were burned away to the midpoint, but the fire did not penetrate internal insulation and mechanisms into the cabin.

Figure 2. Photograph of fire damage to right hand side of fuselage (facing forward).

Inspection of the engine with the powerplant group showed that the oil tank that was now on top of the engine had been compromised. The oil burned adjacent to the fuselage and door 2R. The fuselage in the area showed severe heat damage but no penetrations other than rivet holes and minor cracks. Examination of the accident site and fuel tanks (wings and center) showed no additional postcrash fire involving fuel.

Figure 3. Photograph of Door 2 Right.

Internal Documentation

Lower Lobe/Forward Cargo Compartment

There was evidence of smoke throughout the compartment and in the bilge.

Figure 4. Photograph of forward cargo compartment.

Right-hand cheek

Inspection of the RH cheek area in the forward cargo compartment shows that the heat from the engine fire transferred through the skin. Insulation and ECS riser ducts at STA 825 – 846 and STA 846 – 867 show extensive fire damage.

Figure 5.STA 825 – 888 R/H forward cargo compartment (looking outboard).

Figure 6. STA 825 – STA 846 R/H forward cargo compartment (looking outboard)

Figure 7. STA 825 – STA 846 R/H forward cargo compartment (looking up)

Figure 8. STA 846 - 867 R/H forward cargo compartment (looking outboard)


Figure 9. STA 846 - 867 R/H forward cargo compartment (looking up)

Figure 10. STA 676 - 697 R/H riser ducts appeared undamaged by fire.

Figure 11. STA 676 – 697 L/H rider ducts damaged by fire.

Figure 12. Riser Ducts at STA 825 - 846 L/H riser ducts appeared undamaged by the cabin fire

Aft Wall (STA 998)

Figure 13. Aft wall at STA 998

The aft soft liner had detached from the top edge for the full width and was about 50% open.

ECS Mix Bay (STA 998 – STA 1035)

There was evidence of burn debris from main cabin falling down into the bay leading to minor charring of ECS ducting. The riser ducts from STA 993 L/H had burned and fallen into mix bay.

Ceiling

There was evidence of smoke escaping from the fire in cheek at STA 825 – 867.
There was evidence of heat damage from debris from main cabin at STA 500, STA 625 and STA 951.

The aft cargo compartment was inaccessible due to structural damage.

Main Cabin

Main cabin fire damage extended from just forward of door 1 aft to above door 3. For additional documentation of the fire damage to the main cabin, see the survival factors group chairman's factual report. Burn damage showed evidence of higher temperatures in the areas of the ECS riser ducts at STA 676 – 697 L/H, STA 972 – 993 L/H and STA 972 - 993 R/H. Smoke and heat damage in the crown extended back to the pressure dome.

Flight Deck

Smoke and heat damage was extended into the flight deck. There was an open access panel in the aft ceiling area of the flight deck at STA 246.

Figure 14. Photograph of flight deck.


Figure 15. Ceiling panel in aft area of flight deck

<u>Runway</u>

None of the parts of the airplane outside of the final accident site exhibited any signs of fire or smoke.

Fire Examination Report (Follow-up on-scene visit 8/21-22/13)

Fire Examination:
Present: Al Carlo (Boeing), Nancy McAtee (NTSB) and Rob Ochs (FAA Tech Center)

This effort was to understand the fire growth from external heat source through fuselage (without any penetration through the fuselage) into the cabin to completely consume cabin from door 1 aft to door 3.

Investigators also looked for any contribution from center fuel tank, APU fuel line and hydraulic lines.

Investigators started in the forward cargo compartment looking at the location of greatest damage inside the cheek area opposite of where engine #2 was resting outside the fuselage (STA 825 - 867). Investigators removed systems and insulation to gain access to the skin for inspection. The insulation just beyond the major damage area was in good shape with just the exterior bag material missing on the skin side. Several of the ECS riser ducts and insulation that were not burned were removed for further examination and flammability testing. The ECS ducting from aft of door 3 was examined to see if it had evidence of smoke inside. One duct (door 4 left heater) did have smoke evidence and another duct did not (could not identify, only access to one end).
Parts collected for further examination at FAA Tech Center:

1) ECS Riser ducts from ATA 825 – 847 Left side of airplane including flex hoses (4), Ultem™ ducts from above floor and insulation wrapped around the duct assembly
2) ECS Riser flex duct with burn damage/no burn damage transition from STA 697 LH3) ECS duct with transition section to flexible risers from STA 697 RH
4) Insulation from fwd. lower lobe with burn damage/no burn damage transition
5) Insulation from fwd. lower lobe with no burn damage

The report on the testing of these components is found in the following section "FAA Technical Center Testing Report"

Main Cabin:

The interior surface of door 2R was inspected to verify that the external fire did not enter the cabin through the door. The insulation from behind the packboard area was collected for further examination at the FAA Technical Center. Inspection of the interior of the lavatory aft of door 2R showed a "V" pattern on the aft wall indicating that the fire was along the outboard wall. The same insulation was collected from door 2L. Investigators inspected the floor and sidewall areas and could not find any holes or evidence of a fire coming up through those areas. Investigators gained access to view the top of center wing tank by removing seats and cutting holes in the floor panels. None of the 7 areas showed any signs of fuel or fire.

Survival Factors:

Photographs of the upper and lower packboard brackets on door 1R and door 2R were taken as well as video of door 1R and door 2R operation (opening and closing).

Four sections of airplane with snozzle penetrations were removed for further examination as well as a piece of secondary structure that was hit by the snozzle penetration on the left side of the airplane by door 2.

FAA Technical Center Testing Report

FAA FIRE SAFETY
Fire Test Results for Asiana 214 Materials
February 6, 2014

INTRODUCTION

Several ducts and insulation blankets were removed from Asiana 214 while the fire investigation sub-team was on-site at San Francisco International Airport the week of August 19 2013. Though the fire did not result in injuries to passengers, crew, or first responders, the team felt that the rapid progression of the fire was unusual, due to the lack of an obvious fuselage burn-through from the external fire. On-site investigation resulted in tracing the origin of the internal fire to an ECS riser duct bay at STA 825-846 RH, aft of door 2R, just below the floor line. The right engine detached from the pylon during deceleration, landing nearer to the fuselage. An external fire occurred on the engine fueled by a ruptured engine oil tank. The fire impinged on the fuselage, discoloring and warping the aluminum skin, but did not burn through to the interior. However, below the floor in the cargo bay, severely burned ducts, thermal acoustic insulation, and composite floor beams were found in the right hand cheek area between STA 755.5 and STA 888 behind the cargo compartment liner. The fire was traced from this area, up the riser bay, behind the lavatory, and in to the overhead area. The materials that reside in this inaccessible area of the aircraft are the various ducts and the thermal acoustic insulation blankets. Since the materials in the cheek area on the opposite side of the aircraft were not damaged by fire, they were removed from the same area on the left hand side, STA 755.5 to STA 888 LH. The ducts that were removed had little exterior heat or smoke damage; however there were signs of smoke flowing through the ducts during the fire, as a layer of soot has settled on the inner surfaces of most ducts.

DESCRIPTION OF SALVAGED MATERIALS

Red Duct

The term “Red Duct” is used to describe the flexible hoses that connect the large mixing duct to the overhead area. The ducts are constructed from silicone impregnated fiberglass, and reinforced with a rigid, white spiral material. The ducts are four inches in diameter, and are wrapped with thermal acoustic insulation along portions of the length. Four of these ducts are placed side-by-side just below the ECS riser bay.

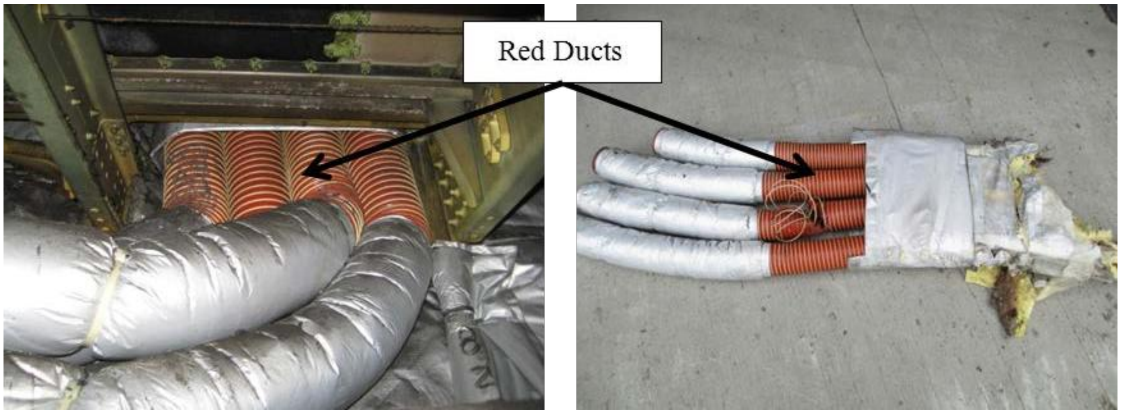

Figure 16. Location of the "Red Ducts" in the cheek area below the floor, going up the ECS riser bay.

Yellow Duct and Insulation

The term "Yellow Duct" is used to describe the large ducts that run parallel to the axis of the aircraft in the cheek area below the floor. These ducts connect the large mixing duct to the red ducts near the riser bay. The yellow duct is a composite material of Kevlar and epoxy construction. The inside diameter is approximately 12 inches. The duct is wrapped in thermal acoustic insulation along most of its length, except for areas where two yellow ducts are joined with a red, silicone coupler. The thermal acoustic insulation on the yellow duct was also recovered for testing. The insulation consisted of a silver film bonded to yellow insulating foam.

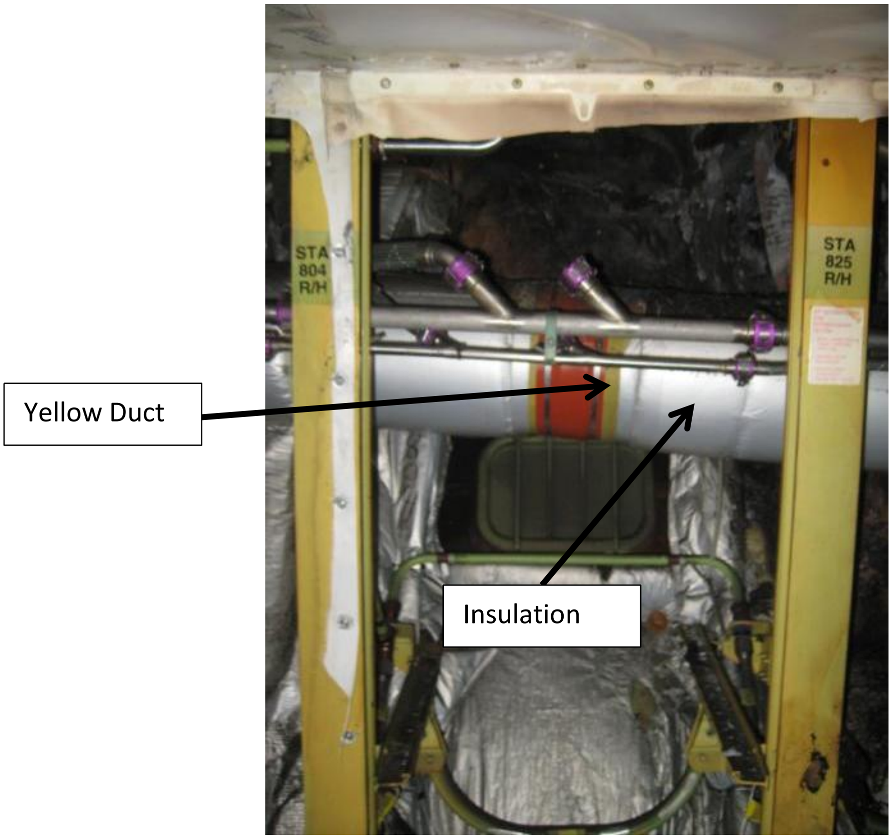

Figure 17. Location of "Yellow Duct" and duct insulation in the cheek area behind the cargo liner and below the floor.

White Duct

The term "White Duct" is used to describe rigid, curved ducts that connect to the flexible red duct behind the sidewall panels above the floor. The white ducts are 4 inches in diameter, and are arranged side-by-side behind the sidewall panel in the ECS riser bay. The white duct is believed to be constructed from Ultem™ thermoplastic polyetherimide (PEI) resin. The white ducts are wrapped in insulation blankets over portions of their lengths. When recovered from the accident aircraft, most of the white ducts in the aircraft were mostly melted and disfigured beyond recognition; only two approximately five-foot sections were undamaged and usable for fire testing.

Figure 18. Photograph of the "White Ducts" recovered from the aircraft. Note that most of the ducts had melted inwards.

DESCRIPTION OF TEST METHODS

12-Second Vertical Bunsen Burner

The oldest and most basic FAA fire test method is the Bunsen burner test. It was mandated in the 1950's for cabin materials to protect against an in-flight fire threat, i.e. a cigarette or matches. A test coupon measuring three inches wide by twelve inches high is cut from the component to be tested, or constructed from identical materials as the component to be tested. The bottom edge of the coupon is exposed to a methane-air premixed Bunsen burner flame, one and one half inches high and three-eighths of an inch in diameter, for twelve seconds, after which time the flame is removed and the test is observed for continued self-sustained burning or flaming dripping. After all flaming has ceased, the sample is removed and the length of burned material is measured. A passing sample must have a burned length of eight inches or less, a self-sustained burn time of fifteen seconds or less, and the flaming drips must not burn for more than three seconds.

A complete description of the test method can be found in the FAA Aircraft Materials Fire Test Handbook, Chapter 1. The Federal Aviation Regulations pertaining to this test method can be found in the Code of Federal Regulations, 14CFR25.853 and part 1 of Appendix F.

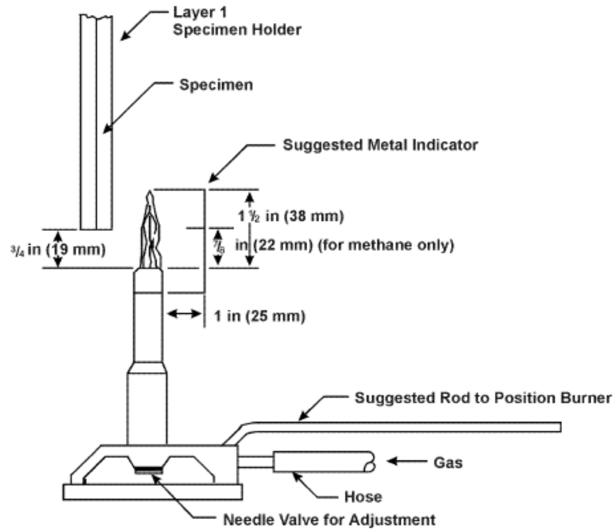

Figure 19. Schematic of the Vertical Bunsen Burner test method.

Heat Release Rate Test for Cabin Materials

This test method, also known as the OSU test, is used to determine the fire hazard of a material by measuring the total heat release and the peak rate of heat release during controlled combustion in a specially designed apparatus. The apparatus consists of a chamber with a vertically mounted radiant heat source opposite to the vertically mounted, approximately six inch square test coupon. Pilot burners are mounted near the bottom and top of the test sample. The bottom burner impinges on the lower coupon surface, initiating sample combustion, while the top burner combusts volatiles that evolve from the heated sample but have not yet reacted or have incompletely combusted. A measured quantity of air flows through the chamber from bottom to top, past the test coupon, and up the exhaust stack. A thermopile is used to measure the temperature rise of the air flow in the chamber during the test. The heat release rate is calculated from the temperature differential measured by the thermopile using a known calibration factor. The calibration is determined by burning a known flow rate of methane gas in the chamber in lieu of a test sample. The heat release rate of methane for various flows is known, so the temperature rise measured during calibration can be used to create the calibration factor for testing. To pass this test, a sample must have both total and peak heat release rate less than 65 kW-min/m^2 and 65 kW/m^2, respectively.

This test method represents the threat of a post-crash fire entering the cabin. The intent is to increase the amount of time available for passengers to escape in the event of a large, fuel-fed external fire. By restricting the total and peak heat release rate of cabin materials, the rate at which volatile gasses collect in the overhead area is decreased, prolonging the time of flashover, or the instantaneous, spontaneous combustion of the cabin environment, after which point survival is highly unlikely. This test method is required for transport category airplanes with passenger capacities of 20 or more. It applies large surface area materials facing the cabin interior, including interior ceiling and wall panels, partitions, galley structures, large cabinets and cabin stowage compartments.

Additional test method details can be found in the FAA Aircraft Materials Fire Test Handbook, Chapter 5. The associated Federal Aviation Regulations can be found in the Code of Federal Regulations 14CFR25.853(d) and Appendix F part 4.

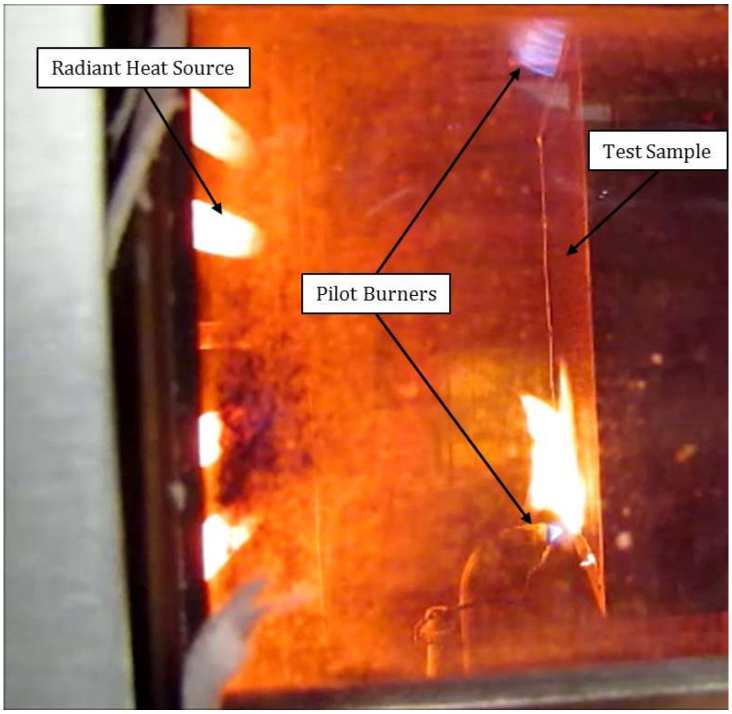

Figure 20. Photograph through the viewing window of the Rate of Heat Release apparatus.

Test Method To Determine the Flammability and Flame Propagation Characteristics of Thermal/Acoustic Insulation Materials

This test method, also known as the Radiant Panel test, was developed to adequately evaluate the fire threat posed by lightweight thermal acoustic insulation films. These materials would pass the Vertical Bunsen Burner test, but in more realistic hidden area fire scenarios the films would burn severely and spread the fire over large areas, as was found during the Swiss Air 111 accident investigation in the late 1990's. The test apparatus consists of a rectangular chamber with a slide-out drawer as the bottom of the chamber. The test sample is a twelve by twenty four inch sample of thermal acoustic insulation, representative of the construction installed in the aircraft. The test sample is placed on the drawer so that it is lying flat and horizontal. Inside the test chamber is a large radiant panel heat source, mounted 60-degrees from the vertical. A premixed propane/air pilot burner is mounted in the chamber that can swivel into and out of test position. The test starts when the sample drawer is slid in to the chamber and the pilot burner is swiveled in to test position, impinging on the test sample. The sample is exposed to the pilot flame and the radiant heat source for fifteen seconds, at which time the pilot burner is swiveled to the standby position. The flame propagation is observed during the test, and the point of furthest flame propagation is noted, as is the time to extinguishment beyond the fifteen second pilot flame time. A sample passes the test if both the flame propagation distance is two inches or less and the after flame time is three seconds or less.

This test method applies to thermal acoustic insulation materials installed in the fuselage of transport category airplanes, including insulation on ducts and damping materials, but not including parts considered too small to contribute to the propagation of a fire. Additional test method details can be found in the FAA Aircraft Materials Fire Test Handbook, Chapter 23, and the associated Federal Aviation Regulation can be found in the Code of Federal Regulations CFR25.856(a) and Appendix F part 6.

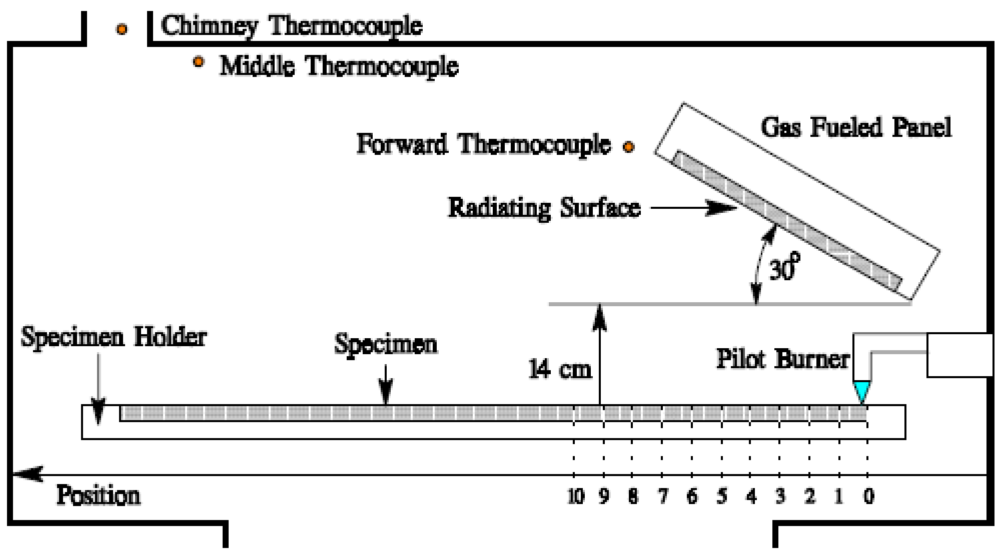

Figure 21. Schematic of the radiant panel flame propagation test apparatus.

Vertical Flame Propagation Test

The vertical flame propagation test is a new test currently being developed to evaluate the flame propagation resistance of structural composite materials in inaccessible areas of the aircraft, i.e. behind sidewall panels and above ceiling panels. The test is representative of a moderately sized fire occurring in an inaccessible area that cannot be extinguished by cabin crew in flight. The test consists of a chamber with a vertically mounted radiant heat source opposite to the test sample door that swings open in the standby position and closed in the test position. A six-flamelet pilot propane/air pilot burner translates to the test position such that the flamelets impinge upon the bottom of the vertical surface of the test sample. The sample is a six by twelve inch coupon representative of the aircraft installation. The test begins when the sample door is closed, exposing the vertical sample surface to the radiant heat source and to the pilot flames. The pilot burner is translated out at fifty seconds, after which time the sample is allowed to continue to burn. The test is complete when the sample self-extinguishes. The sample is removed, and a burn length measurement is made. Currently, no pass/fail criteria have been developed, as the test method is still under development. For comparison, aerospace-grade 350°F-cure carbon epoxy composites, typical of fuselage construction for modern composite aircraft, have average burn length of two inches for an eight ply quasi-isotropic construction, while samples greater than twelve ply thickness have no measureable burn length beyond the pilot flamelet footprint. More information on this test method can be found in presentations given at the International Aircraft Materials Fire Test Working Group, http://www.fire.tc.faa.gov/materials.asp.

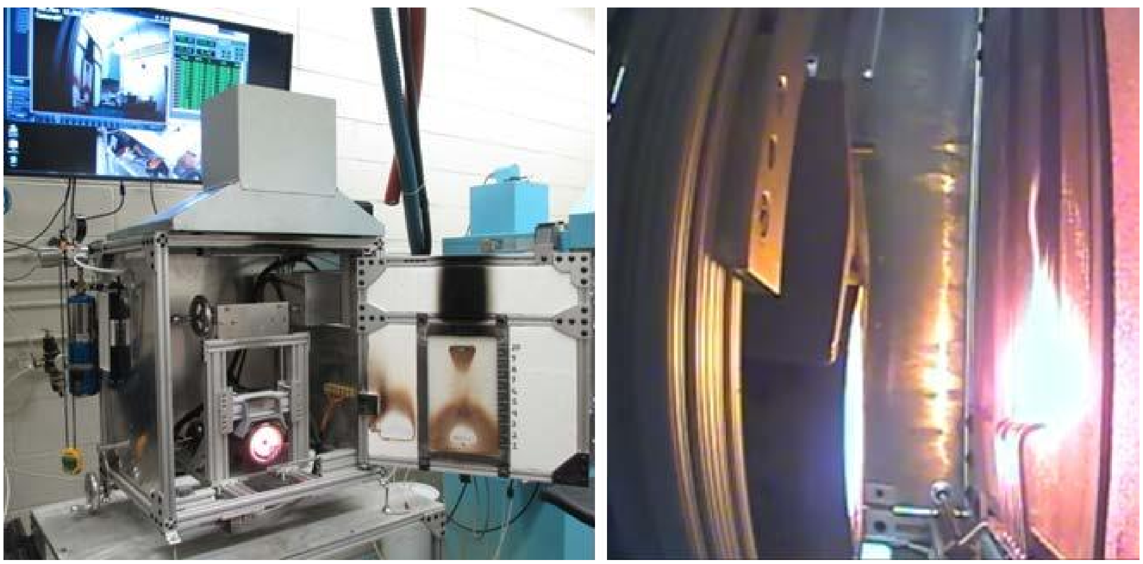

Figure 22. Photograph of the vertical flame propagation test apparatus (left) and a test in progress (right).

Microscale Combustion Calorimeter

The Microscale Combustion Calorimeter (MCC) was developed by the Federal Aviation Administration Fire Research program to evaluate various flammability properties from milligram-sized material samples. The apparatus heats the small sample to temperatures in the range of 1,000°C in an inert nitrogen gas stream, thus releasing combustible constituents without reacting. The gas stream is then mixed with excess oxygen in the combustion chamber and oxidized at high temperature. Oxygen consumption calorimetry is used to determine the quantity of oxygen used during combustion. Published experimental data has shown that for typical organic molecules, the net heat of complete combustion is 13.1 ± 0.6 kJ/g-O_2, therefore the heat release rate can be determined by measuring the amount of oxygen consumed during combustion. Other material properties can be determined from the MCC test, including heat release capacity, heat of combustion, and pyrolysis temperature. The MCC is not a required fire test for airplane certification, but rather is a research tool for materials development. It is currently an ASTM standard test method, ASTM D7309, entitled “Standard Test Method for Determining Flammability Characteristics of Plastics and Other Solid Materials Using Microscale Combustion Calorimetry.”

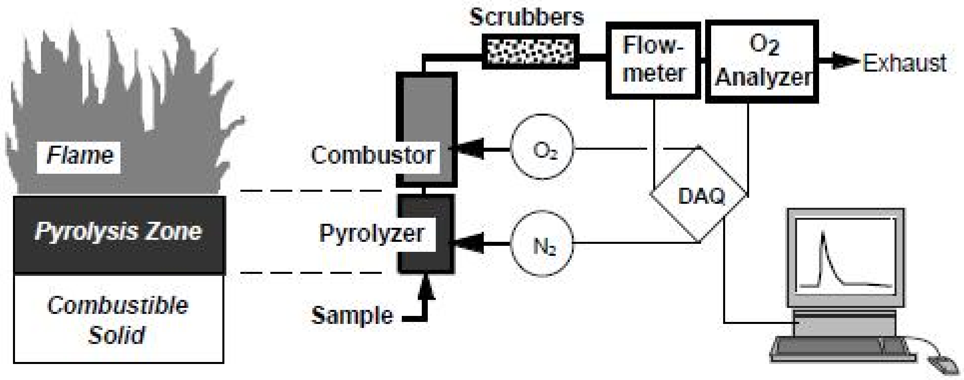

Figure 23. Schematic of the Microscale Combustion Calorimeter.

Applicability of Federal Aviation Regulations to Asiana 214

Air ducting in this aircraft was required by FAR Part 25 Sec. 25.853(a) and Appendix F25.1 to meet the twelve second vertical Bunsen burner test. Thermal acoustic insulation was required by FAR Part 25 Sec. 25.856(a) and Appendix F25.6 to meet the radiant panel flame propagation test.

TEST RESULTS

The following tests were conducted at the Federal Aviation Administration William J. Hughes Technical Center Fire Safety Branch during the months of November and December, 2013.

12-second Vertical Bunsen Burner

The test results from the Bunsen burner tests for all materials are presented in Figure 9 and Figure 10, displaying average burn length and average after flame time, respectively. Three samples of each material were tested, and the results were averaged. All materials passed the test, as the maximum allowable burn length is eight inches, and the maximum allowable after flame time is fifteen seconds, and there were no flaming drips. All of the materials tested were required to meet the vertical Bunsen burner test according to 25.853.

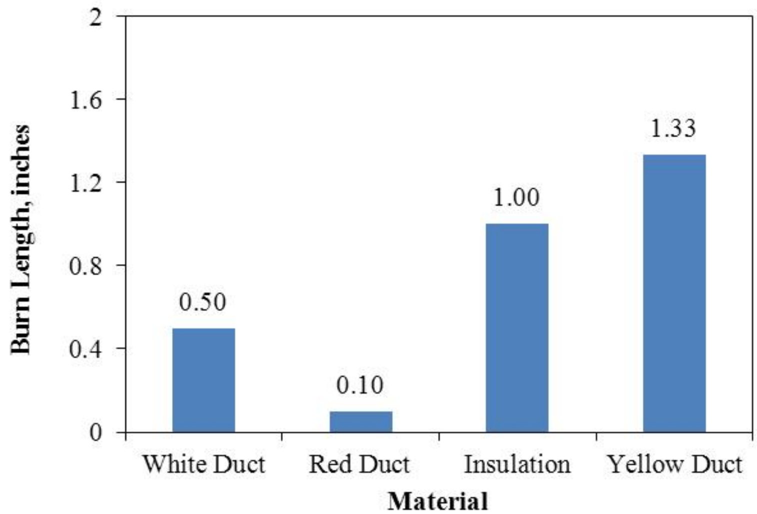

Figure 24. Average burn length results from the twelve second vertical Bunsen burner test.

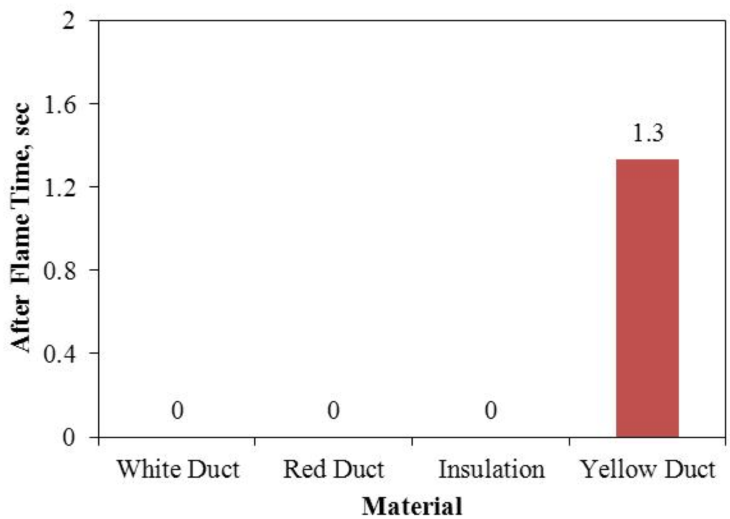

Figure 25. Average after flame time results from the twelve second vertical Bunsen burner test.

Rate of Heat Release (OSU)

The results from the OSU testing are presented in Figure 11 and Figure 12, displaying the average peak heat release rate and average total heat release rate, respectively. Three samples of each material were tested, and the results were averaged. Three of the materials, white duct, yellow duct, and insulation passed both peak and total heat release, while the red duct failed both peak and total heat release, having values higher than 65. It must be noted that none of these materials are required to meet the OSU test for certification; it was only used to determine the effect of a more severe fire test method on materials that all pass the vertical Bunsen burner test.

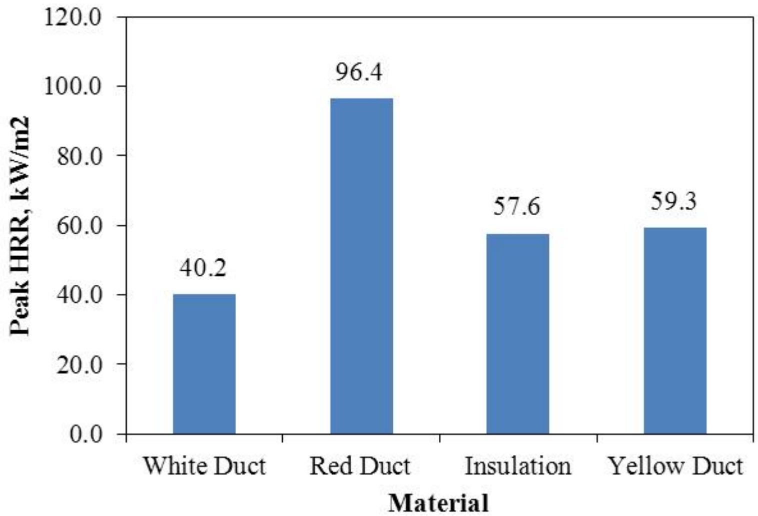

Figure 26. Average peak heat release rate test results.

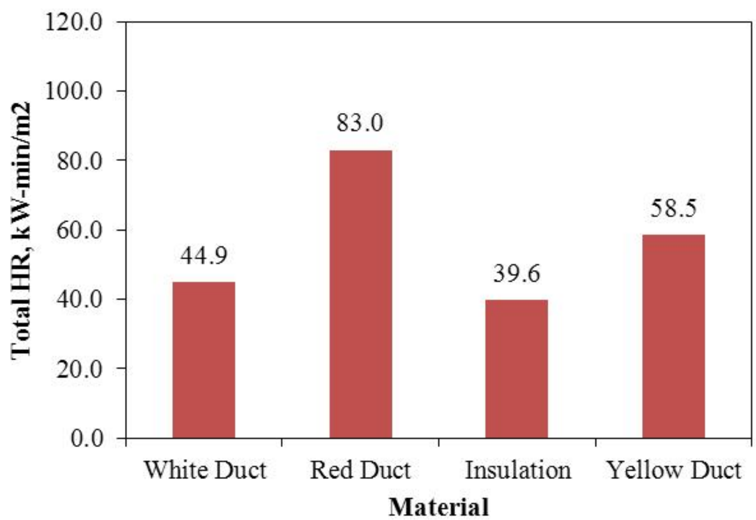

Figure 27. Average total heat release rate test results.

Radiant Panel Flame Propagation Test

The results from the radiant panel test are presented in Figure 13 and Figure 14, displaying measured flame propagation and observed after flame time, respectively. Only the insulation material was tested in the radiant panel test, as it is the only material of those salvaged that is required to meet this test method on this airplane. Since the radiant panel requires relatively large sample sizes, twelve by twenty four inches, only two tests were performed, one with the film side facing up and the other with the insulating foam side facing up. Regardless of the side tested, both tests had measured flame propagation less than two inches and observed after flame time less than three seconds.

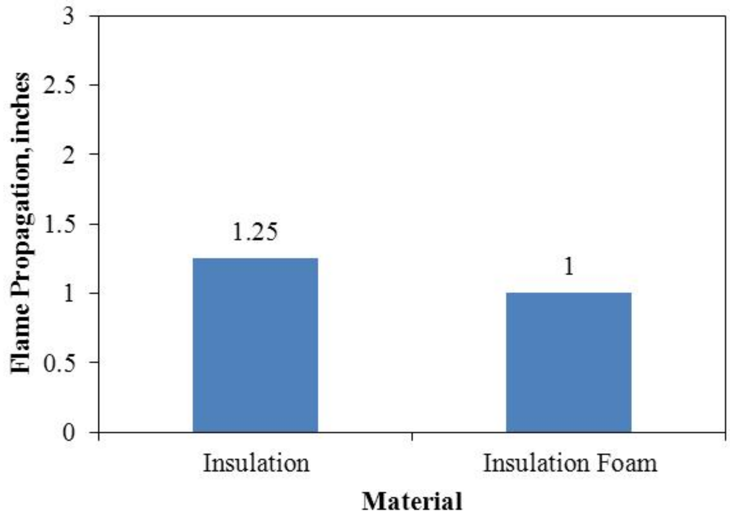

Figure 28. Measured flame propagation for the insulation samples.

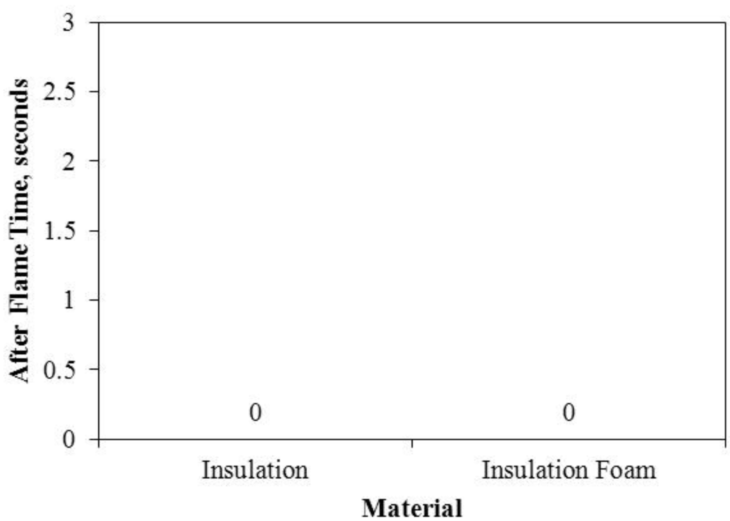

Figure 29. Observed after flame time for the insulation samples.

Vertical Flame Propagation Test

The results from the vertical flame propagation test are presented in Figure 15 and Figure 16, displaying the average burn lengths and average after flame times, respectively. Only duct materials were tested in this apparatus, as there were not sufficient quantities of insulation to test and the insulation was already found to pass the stringent radiant panel test for insulation. The results from the vertical flame propagation test indicate that the red duct was more likely to propagate flames under these conditions. Similar to the OSU results, the red duct could be considered a material of poor fire resistance when tested to conditions more severe than the vertical Bunsen burner test.

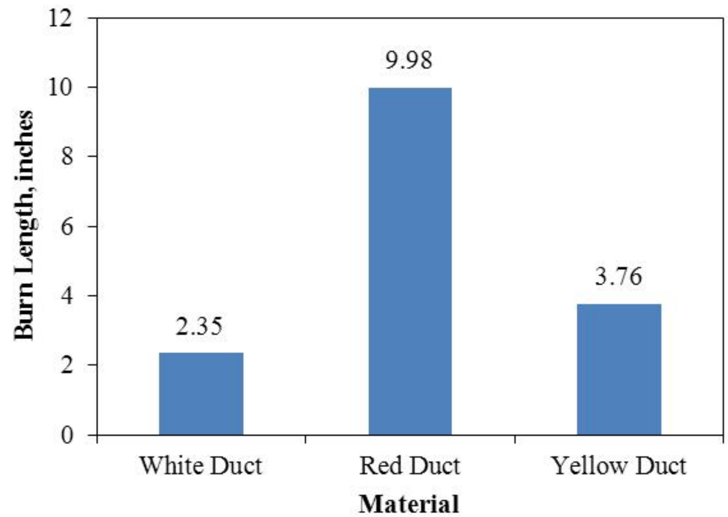

Figure 30. Average burn lengths for the duct materials tested in the vertical flame propagation test.

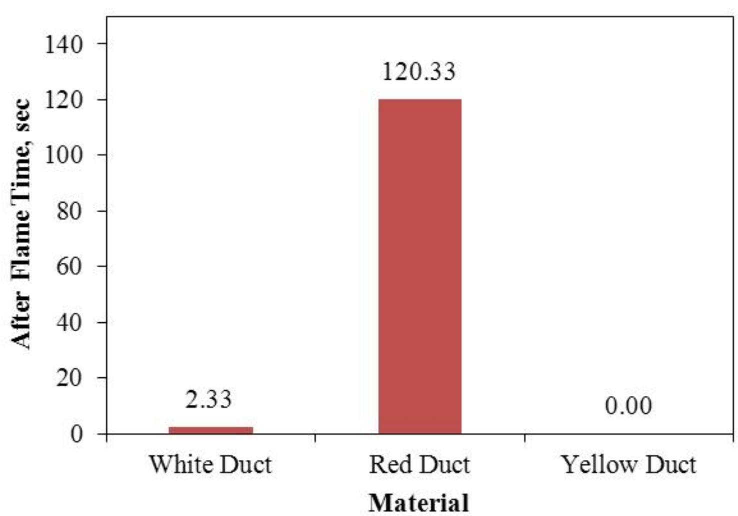

Figure 31. Average after flame times for the duct materials tested in the vertical flame propagation test.

Microscale Combustion Calorimeter

The results from the Microscale Combustion Calorimeter are presented in Figure 17 through Figure 20, displaying total heat release, peak heat release rate, pyrolysis temperature, and heat release capacity. Since the sample size is small for this test, the red duct was separated into two different samples – the red silicone fiberglass duct and the white reinforcing spiral ring, as indicated in Figure 21. The figures indicate that the white reinforcing spiral wire is the most flammable of all materials, measuring the highest total heat release, peak heat release rate, and heat release capacity.

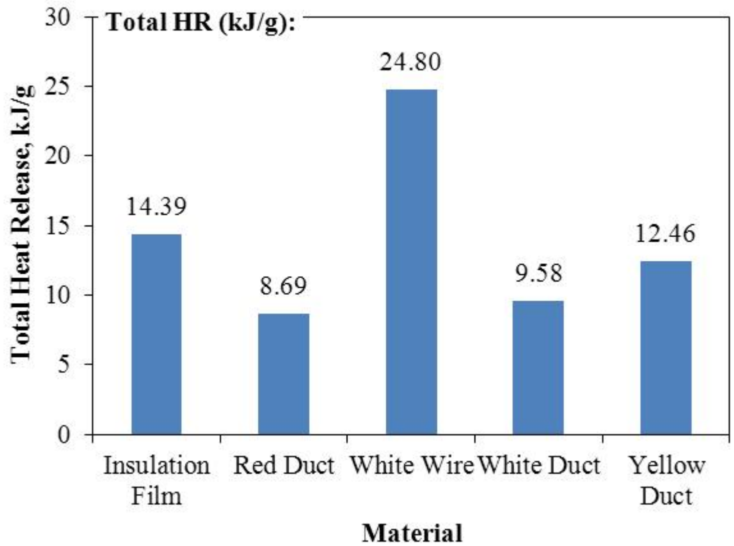

Figure 32. Total heat release as measured by the Microscale Combustion Calorimeter.

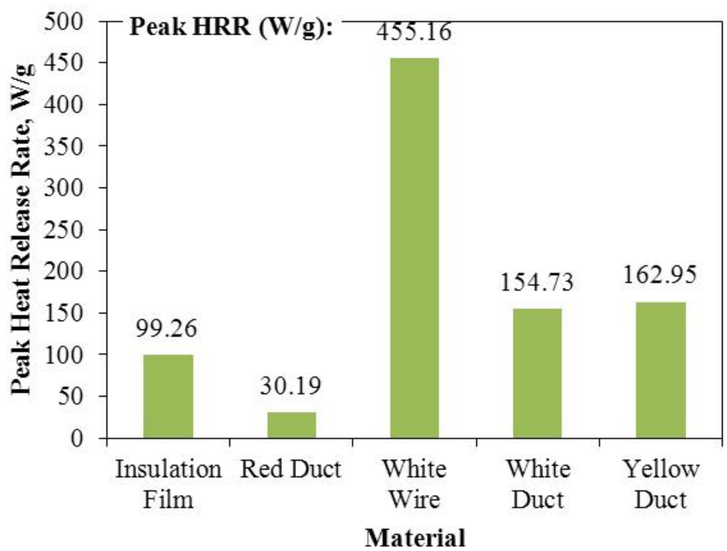

Figure 33. Peak heat release rate as measured by the Microscale Combustion Calorimeter.

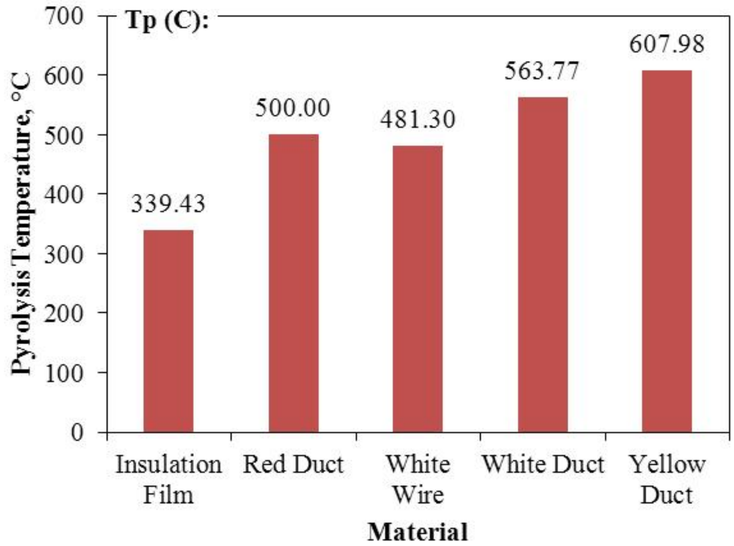

Figure 34. Pyrolysis temperature as measured by the Microscale Combustion Calorimeter.

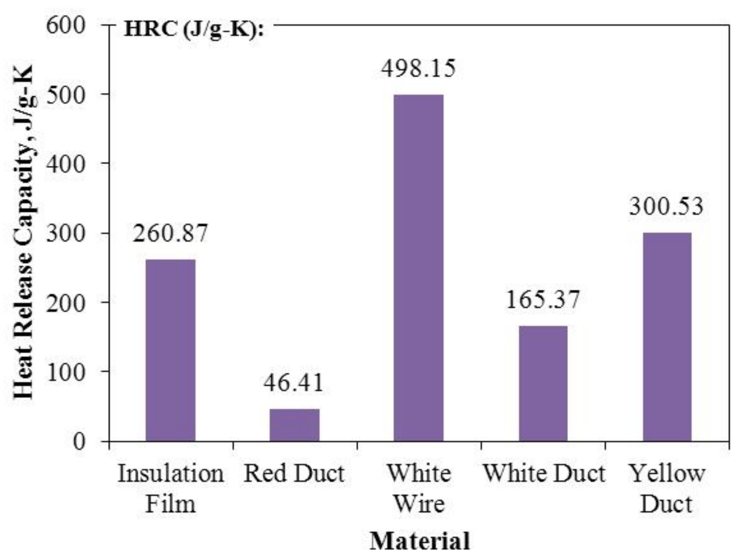

Figure 35. Heat release capacity as measured by the Microscale Combustion Calorimeter.

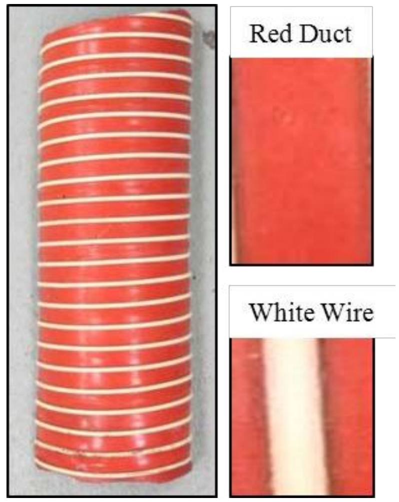

Figure 36. Red duct separated into two individual samples for MCC testing.

DISCUSSION

Of all the materials tested, the red flexible duct displayed the poorest fire performance when introduced to test methods more severe than the vertical Bunsen burner test that is required for certification. The MCC test results indicated that the white reinforcing spiral wire was actually the most flammable component of the red duct, and when it begins to combust a significant amount of heat is released. This behavior was also observed in the OSU and the vertical flame propagation apparatus, where the radiant heater added significantly more energy to the surface of the sample, elevating the temperature of the red duct and white wire, resulting in self-sustaining flaming combustion and flame propagation along the sample surface. Although the red duct displayed poor fire performance in these tests, the criteria for certification still remains a twelve second vertical Bunsen burner test. Therefore, the material meets and exceeds the current certification criteria for flammability.

ACRONYMS

CFR: Code of Federal Regulations
ECS: Environmental Control System
FAA: Federal Aviation Administration
FAR: Federal Aviation Regulations
HRR: Heat Release Rate
MCC: Microscale Combustion Calorimeter
OSU: Ohio State University rate of heat release apparatus